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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
XIAODONG	LI	KIRKLAND, WA

Additional inventors are being named on the 1 *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHODS AND APPRATUS FOR OVERLAYING MULTI-CARRIER AND DIRECT-SEQUENCE SPREAD SPECTRUM SIGNALS IN A BROADBAND WIRELESS COMMUNICATION SYSTEM

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

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ENCLOSED APPLICATION PARTS ***(check all that apply)***

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☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☒ Applicant claims small entity status. See 37 CFR 1.27.

☒ A check or money order is enclosed to cover the filing fees.

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Respectfully submitted,

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TELEPHONE 425 451 8278

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Methods and Apparatus for Overlaying Multi-Carrier and Direct Sequence Spread Spectrum Signals in a Broadband Wireless Communication System

1 Background of the Invention

In broadband wireless communications, Direct Sequence Spread Spectrum (DSSS) and Multi-Carrier (MC) techniques are commonly used. Both the DSSS and MC schemes have their own advantages. For instance, DSSS is inherently capable of supporting multi-cell and multi-user access applications through the use of orthogonal spreading codes. By its nature of interference averaging, initial access of the physical channel and frequency planning are relatively easier to be done in DSSS system. From here on, we will use SS to refer to DSSS.

As one example of MC, Orthogonal Frequency Division Multiplexing (OFDM) with cyclic prefix insertion mitigates inter-symbol interference (ISI) by extending the signal period as the data is multiplexed on orthogonal sub-carriers. As such, it converts a frequency selective channel into a number of parallel flat fading channels which can be easily equalized with simple one-tap equalizers. The (de)modulator can be executed efficiently via the fast Fourier transform (FFT) with much lower cost. In general, MC is capable of supporting broadband application with a higher spectral efficiency and at the same time not severely impacted by multi-path propagation in wireless environment.

On the other hand, both of them have their weaknesses. For example, wideband spread spectrum systems with orthogonal spreading codes suffer severely due to the loss of orthogonality by multi-path propagation therefore yielding low spectral efficiency, while multi-carrier systems need to be carefully designed to operate in a multi-user and multi-cell environment.

2 Summary of the Invention

This invention is an advanced scheme that coordinates MC and SS signaling in one system where both signals are intentionally overlaid together in both time and frequency domains. It takes advantages of both MC and SS techniques while mitigating their weaknesses. The MC signal is used to carry broadband data signal due to its high spectral efficiency, while the SS signal is used for special purpose processing, such as initial random access, channel probing, and short messaging, in which cases properties such as signal simplicity, self synchronization, and performance under severe interference are more important. The system is designed in such a way that both the MC signal and the SS signal are distinguishable in normal operations, i.e., the interferences between the two signals do not degrade their respective expected performance.

Unlike a typical CDMA system where the signals are designed to be orthogonal in code domain, or a typical OFDM system where the signals are designed to be orthogonal in frequency domain, this invention intentionally overlay the MC signal, which has no spreading or a very low spreading factor to achieve high spectrum efficiency, and the SS signal, which has a much lower power level than that of the MC signal.

In one embodiment, the MC signal is modulated on subcarriers in the frequency domain while the SS signal is modulated in the time domain. A special case is that the modulation symbol on the SS sequence is 1; that is, the sequence is unmodulated. Correspondingly, the MC signal is demodulated in the frequency domain and the SS signal is demodulated in the time domain.

This invention further provides the apparatus or means to implement the aforesaid design process and methods in a broadband wireless multi-access and multi-cell network using advanced techniques, such as transmit power control, spreading signal design, and iterative cancellation.

The multi-carrier system mentioned in this invention can be of any special formats such as OFDM, or Multi-Carrier Code Division Multiple Access (MC-CDMA). The invention can be applied to downlink, uplink, or both, where the duplexing technique can be either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD).

3 Brief Description of the Drawings

The present invention will be understood clearly from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1: The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Data subcarriers can be grouped into subchannels.

Figure 2: The radio resource is divided into small units in both the frequency and time domains: subchannels and time slots. The basic structure of a multi-carrier signal in the time domain is made up of time slots.

Figure 3: Frame structure of an exemplary OFDM system. A 20ms frame is divided into four 5ms subframes. One subframe consists of six time slots and two special periods.

Figure 4: Three examples of the subframe structure in the exemplary OFDM system: one symmetric configuration and two asymmetric configurations.

Figure 5: Slot structure of the OFDM system and the overlay system. One 800 us time slot is comprised of 8 OFDM symbols. It is overlaid by SS signals in time domain. Two guard periods GP1 and GP2 are allocated for the SS signal.

Figure 6: The illustration of MC signals overlaid with SS signals in the frequency domain where the power level of the SS signal is much lower than that of the MC

signal. The subcarriers in a subchannel are not necessarily adjacent to each other in frequency domain.

Figure 7: The same illustration as in Figure 6 where not all MC subchannels are occupied.

Figure 8: Transmitter structure of MC and SS overlay system where the MC signal and SS signal are added together before the Digital to Analog converter.

Figure 9: Receiver structure of MC and SS overlay system. The composite signal is processed by the MC receiver and SS receiver, respectively.

Figure 10: SS signal is used as initial random access by MS_j in the overlay system. At the mean time, MS_l and MS_k are transmitting MC signal to the base station (BS_i).

Figure 11: A mobile station can send the SS signal to its current serving base station, or other base station. The latter case is especially helpful in hand-off process. In this figure, the mobile station MS_k is communicating with BS_i using MC signal while transmitting SS signal to BS_k.

Figure 12: Using interference cancellation technique to cancel the interfering SS signal in the composite signal to obtain a cleaner MC signal.

Figure 13: The SS signal and the MC signal can be fully overlaid or partially overlaid at MC symbol or slot boundary in time domain.

Figure 14: Illustration of an SS signal with a high Peak to Average Ratio in frequency domain that causes strong interference to certain MC subcarriers.

Figure 15: Using spectrum nulls in SS signal to protect an MC control subchannel.

Figure 16: Spectrum control for SS signal using simple sub-sampling method.

Figure 17: SS signal is used for channel probing or to carry short message. In this case, MS_j is transmitting both MC signal and SS signal to the base station BS_i. It is also under closed loop power control with BS_i.

Figure 18: A typical channel response in the time and frequency domains. By estimating the peaks of a channel response in the time domain, the channel profile in the frequency domain can be obtained.

4 Detailed Description

4.1 Multi-Carrier Communication System

The physical media resource (e.g., radio or cable) in a multi-carrier communication system can be divided in both the frequency and time domains. This canonical division provides a high flexibility and fine granularity for resource sharing.

The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Within a particular spectral band or channel, there are a fixed number of subcarriers. There are three types of subcarriers:

1. Data subcarriers, which carries information data;
2. Pilot subcarriers, whose phases and amplitudes are predetermined and made known to all receivers and which are used for assisting system functions such as estimation of system parameters; and
3. Silent subcarriers, which have no energy and are used for guard bands and DC carrier.

The data subcarriers can be arranged into groups called subchannels to support scalability and multiple access. The carriers forming one subchannel are not necessarily adjacent to each other. Each user may use part or all of the subchannels. The concept is illustrated in Figure 1.

The basic structure of a multi-carrier signal in the time domain is made up of time slots to support multiple-access. The resource division in both the frequency and time domains is depicted in Figure 2.

4.2 An Exemplary MC System

Here we use OFDM as the special case of a MC system. The system parameters for the uplink under consideration are listed in Table 1.

Data Rate	2, 4, 8, 16, 24 Mbps
Modulation	QPSK, 16-QAM
Coding rate	1/8, 1/4, 1/2, 3/4
IFFT/FFT size	1024
OFDM symbol duration	100 us
Guard interval	11.11 us
Subcarrier spacing	9.765625 kHz
System sampling rate (fs)	11.52 MHz
Channel spacing	10 MHz

Table 1: Uplink system parameters

The frame structure of the system under consideration is shown in Figure 3. It consists of four subframes where each subframe consists of six time slots and two different special periods.

The six time slots in one subframe can be configured as either uplink or downlink slots symmetrically or asymmetrically. Three examples of the subframe structure are shown in Figure 4. Within one time slot, there are eight OFDM symbols as shown in Figure 5.

4.3 Detailed Description of a MC and SS Overlay System

To illustrate the overlay of the MC and SS signals, in Figure 5 the SS signal is plotted to overlap with the MC signal in time domain. The overlaid signal can be aligned at the boundary of MC slot or MC symbol when they are synchronized (for example, SS signal #k in Figure 5), or not aligned when they are not synchronized (for example, SS signal #j in Figure 5).

In one embodiment, the SS signal is placed at the period of cyclic prefix of the OFDM symbol.

In frequency domain, the overlay of the MC spectrum and SS spectrum is depicted in Figure 6. Figure 7 illustrates the scenario that some MC subchannels are not energized.

In one embodiment, the MC signal is modulated on subcarriers in the frequency domain while the SS signal is modulated in the time domain. A special case is that the modulation symbol on the SS sequence is 1; that is, the sequence is unmodulated. Correspondingly, the MC signal is demodulated in frequency domain and the SS signal is demodulated in time domain.

In Figure 8, the top branch is an OFDM transmitter. The bottom branch is the spread spectrum transmitter. A digital attenuator (G_1) is used for the SS signal to adjust its transmitted signal level relative to the MC signal. The two signals are overlaid in digital domain before converting to the composite analog signal. A second analog variable gain (G_2) is used after the D/A converter to further control the power level of the transmitted signal. When MC signal is not present, both G_1 and G_2 will be applied to the SS signal to provide sufficient transmission dynamic range. G_2 can be realized in multiple circuit stages.

Figure 9 illustrates the receiver structure of the overlay system. At the receiver side, the A/D converter first converts the received analog signal to digital signal after the automatic gain control (AGC). To detect whether the SS signal is present, the signal is then despread with a matched filter or a correlator using the access sequence to check if the correlation peak exceeds a predefined threshold. The information from SS receiver will then be used to decode the mobile station's signature in the case of initial random access, derive the channel information in the case of channel probing, or decode the information bit in the case of short messaging.

In one embodiment, a rake receiver is used in SS receiver to improve its performance in multi-path environment.

In one embodiment, the MC signal is processed as if no SS signal is present. In another embodiment, advanced interference cancellation technique can be applied to the composite signal to cancel the SS signal from the composite signal thus maintaining almost the same MC performance [see Section 4.3.2].

The transmitted composite signal for user i can be represented by:

$$s_i(t) = G_{i,2} * [G_{i,1} * s_{i,SS}(t) + b_i * s_{i,MC}(t)] \tag{1}$$

where b_i is 0 when there is no MC signal and is 1 when MC signal is present. Similarly, $G_{i,1}$ is zero when there is no SS signal and varies depending on the power setting of SS signal relative to MC signal when SS signal is present. $G_{i,2}$ is used to control the total transmission power for user i. The received signal can be represented by:

$$r(t) = \sum_{i=1}^{M} s_i(t) + N + I \tag{2}$$

where M is the total number of mobile station actively communicating with the current base station, N is the Gaussian noise, and I is the total interference from all the mobile stations in current and other base stations.

Denoting the received power of MC signal as P_{MC} and the received power of SS signal as P_{SS}, the signal to interference and noise ratio (SINR) for the MC signal is:

$$SINR_{MC} = P_{MC} / (N+I) \tag{3}$$

when SS signal is not present; and is

$$SINR'_{MC} = P_{MC} / (N+I+P_{SS}) \tag{4}$$

when SS signal is present. The system is designed such that the $SINR'_{MC}$ meets the SINR requirement for the MC signal and its performance is not compromised in spite of the interference from the overlaid SS signal.

In one embodiment, the SS signal is power controlled such that P_{SS} is well below the noise level, N.

On the other hand, the SINR for the SS signal is

$$SINR_{SS} = P_{SS} / (N+I+P_{MC}) \tag{5}$$

Denoting the spreading factor for the SS signal as K_{SF}, the effective SINR for one symbol after despreading is:

$$SINR'_{SS} = P_{SS} * K_{SF} / (N+I+P_{MC}) \tag{6}$$

$SINR'_{SS}$ needs to be high enough to meet the performance requirement when detecting or decoding the information conveyed in SS signal. In one embodiment, K_{SF} is chosen to be 1000 such that the SS signal is boosted with 30dB spreading gain after despreading.

A mobile station can send the SS signal to its current serving base station, or other base station. The latter case is especially helpful in hand-off process, as illustrated in Figure 11.

4.3.1 Power Control

As discussed above, one key design issue is to minimize the power of the SS signal to reduce its interference to the MC data signal. In one embodiment, the initial power setting of a mobile station, T_{MS_tx} (in dBm), is set based on path loss, L_{path} (in dB), and the desired received power level at the base station, $P_{BS\_rx\_des}$ (in dBm),

$$T_{MS\_tx} = P_{BS\_rx\_des} + L_{path} - C_1 - C_2 \qquad (7)$$

C_1 (in dB) is set to a proper value so that the SINR of the MC as specified in equation (4) meets its requirement. C_2 (in dB) is an adjustment to compensate for the power control inaccuracy.

The open loop power control inaccuracy is mainly caused by the discrepancy between the estimated path loss by the mobile station and the actual path loss.

In one embodiment, C_1 is set to 9dB for MC using QPSK modulation with ½ error control coding or 15dB for MC using 16QAM modulation with ½ error control coding. C_2 is set to 10dB or 2dB depending on whether the mobile station is under open loop power control or closed loop power control.

Power control for the SS signal also eases the spectrum mask requirement for SS signal because the SS signal level is much lower than that of the MC signal.

With the total power offset of $C_1 + C_2$ subtracted from the initial transmission power of SS signal, the spreading factor of the SS signal needs to be set high enough (e.g., 512 (27dB) or higher) so that the SS signal can be detected in normal condition. This requires sufficient number of bits of the A/D converter at the base station, for example, 12 bits.

As one embodiment, the D/A converter at the mobile station uses 12 bits, among which 8 bits are targeted for MC signal (assuming 3 bits is reserved for MC peak to average consideration). Thus, there are enough bits left for SS signal even with significant attenuation relative to the MC signal.

4.3.2 Canceling the Interference of SS Signal to the MC Signal

In one embodiment, the base station employs interference cancellation technique to cancel the SS interference to the MC signal. First, the SS signal is detected by the SS receiver; then it is subtracted (decision directed) from the total received signal to obtain a cleaner MC data signal, as illustrated in Figure 12.

In another embodiment, multiple step iterative cancellation can be applied to further improve the effectiveness of the interference cancellation.

4.3.3 SS Signal D sign

SS sequences are chosen to have good autocorrelation and cross-correlation properties (i.e., with high peak to sidelobe ratio).

In one embodiment, pulse shaping is applied to restrict the spectrum mask of SS signals and to reduce impacts on the MC signals in the frequency domain. For example, the transmitter pulse-shaping filter applied to the SS signal can be a root-raised cosine (RRC) with roll-off α in the frequency domain. The impulse response of the chip impulse filter $RC_0(t)$ is

$$RC_0(t) = \frac{\sin\left(\pi \frac{t}{T_C}(1-\alpha)\right) + 4\alpha \frac{t}{T_C} \cos\left(\pi \frac{t}{T_C}(1+\alpha)\right)}{\pi \frac{t}{T_C}\left(1-\left(4\alpha \frac{t}{T_C}\right)^2\right)}$$

where the roll-off factor α and T_c is the chip duration.

The SS signal and MC signal may be aligned at the symbol (or slot) boundary when they are synchronized, or partially overlap in time domain when they are not synchronized, as shown in Figure 13, where SS signal #m fully overlaps with a MC symbol (or slot) in time domain while SS signal #n overlaps with the MC symbol (or slot) only partially.

The sequence that is used to spread the SS signal has to be carefully designed to avoid the cases where the SS signal may have a high Peak to Average ratio (PAR) in the frequency domain and its spikes in the frequency domain may cause severe interference to some MC subcarriers, as illustrated in Figure 14. In one embodiment, the SS sequence is designed such that the sequence, in partial or in full, has low PAR in the frequency domain using signal processing techniques, such as a PAR reduction algorithm. Either binary or non binary sequences can be used. In one embodiment, Golay complementary sequences, Reed-Muller codes, or the codes designed with similar construction methods are used to control the PAR of SS sequences in the frequency domain, thereby limiting the interference of SS signals to MC signals, which are demodulated in the frequency domain. In one embodiment, guard periods are added to the SS signal which overlaps with one MC symbol, as shown by SS signal #p in Figure 13. The guard periods ensure that a well-designed SS sequence (with low PAR in frequency domain) causes little interference to the MC subcarriers even when there is time misalignment in SS signal relative to the OFDM symbol period.

Within MC subcarriers, the control subcarriers are more important than the data subcarriers and may need to have a better protection in the overlay system.

In one embodiment, the SS sequence is carefully designed to have spectrum nulls at MC control subchannels to avoid excess interference to the uplink MC control signals, as illustrated in Figure 15. One such scheme is to use sub-sampling such that the chip rate of the SS signal is 1/2 or 2/3 of the system sampling rate, which means the SS spectrum will only occupy the center portion with a width of 5.76MHz or 7.68MHz out of

the 10MHz available spectrum (as shown in Figure 16). Its interference to the MC subcarriers over the rest of the spectrum will be much lower where the MC subchannels carrying control information or using higher modulation subcarriers (such as 16QAM) can be placed.

4.4 Initial Random Access Using the Overlay Scheme

As one embodiment of the invention, the SS signal is used for initial random access and MC signal is used by multiple mobile stations to transmit high rate data and related control information, as illustrated in Figure 10, where the mobile station MS_j is transmitting its initial access SS signal simultaneously with the MC signals from other mobile stations (in this case, MS_l and MS_K) to the base station BS_i.

In the initial random access of a multi-carrier multiple access system, a mobile station can not transmit directly onto the control subchannel due to the fact that its transmission time and power have not been aligned with other mobile stations. When this mobile station powers up or wakes up from the sleep mode, it first listens to the base station's broadcasting channel and finds the available random access SS channels. Then, it sends the initial random access signal over the designated SS channel with certain signature code. The signature sequence that the mobile selects is from the sequence set that is designated to the corresponding base station, which is broadcasted to all the mobile stations by each base station. The initial access SS signal arrives at the base station together with MC signals from other mobile stations carrying data and control information. The initial power level of the SS signal is based on the open power loop control settings [See Section 4.3.1]. Sufficient guard period is reserved in SS signal to account for initial time alignment uncertainty, as shown in Figure 5.

If the base station successfully detects the SS signal, it sends the acknowledgement (ACK) carrying information such as the mobile station's signature and its power and time adjustments on the downlink control channel in the next available timeslot. The mobile station whose transmission signature matches that in the acknowledgement then moves to the designated uplink MC control channel using the assigned time and power values and further complete the message transmission. If no feedback is received at the mobile station after a pre-defined number of slots, it assumes that the access slot was not detected by the base station, and will ramp up the transmission power of the SS signal by one step and re-transmit it, until it reaches the maximum allowable transmit signal power or the maximum retry times. In one embodiment, the power ramping step of the mobile station is set to be 1dB or 2dB which is configured by the base station on the downlink broadcasting channel. The maximum allowable transmit signal power and the retry times are also controlled by the base station depending on the uplink modulation/coding scheme and available access channels.

During the initial random access, the SS signal can also be used for channel probing and short messaging [See Section 4.5 and 4.6].

4.5 Channel Probing Using SS in the Overlay System

In one embodiment of the invention, the SS signal is used to assist the estimation of the channel characteristics. In this case, the mobile station is already synchronized in time and frequency with the base station, and its transmission of MC signal is under closed-loop power control with the base station. In Figure 17, the mobile station MS_j is transmitting its SS signal simultaneously with its own MC signal. Other mobile stations (in this case, MS_l and MS_K) are transmitting either MC signal or SS signal to the base station BS_i.

A typical channel response in the time domain and frequency domain for a broadband wireless system is shown in Figure 18. Using a matched filter in the SS receiver at the base station, the peaks of a channel response in time can be detected, which in turn can be used to obtain the channel profile for the mobile station in both the frequency and time domains.

When the closed loop power control is used, the initial power settings will be much more accurate than by using open loop power control alone. Thus, the margin reserved for power control inaccuracy can be reduced to a much smaller value. Furthermore, a bigger spreading factor can be used since no data information needs to be conveyed in the SS signal. This leaves a dynamic range large enough for detecting multi-path peaks from the output of the match filter or correlator, thereby generating a better channel profile. When and how often a mobile station should send the SS signal for channel probing is configurable by the network or the mobile station.

In one embodiment, the base station dictates the mobile station to transmit the channel probing SS when it needs an update of the mobile station's channel characteristics.

In another embodiment, the base station polls the mobile station during its silent period and get an update of the mobiles station's information such as transmission timing and power from the probing SS signal.

In one embodiment, the channel profile information is used by the base station to determine the proper modulation/coding and pilot pattern.

In another embodiment, the channel profile information is used for advanced antenna techniques such as beamforming.

In one embodiment, channel probing with the SS signaling is performed without close loop power control or time synchronization.

4.6 Short Message Using SS in the Overlay System

In another embodiment of the invention, the SS signal is used to carry short message. In this case, the mobile station is already synchronized in time and frequency with the base station, and its transmission of MC signal is also under closed-loop power control with the base station. As shown in Figure 17, the mobile station MS_j is transmitting its SS signal carrying short message simultaneously with its own MC signal. Other mobile stations (in this case, MS_l and MS_K) are transmitting either the MC signal or SS signal to

the base station BS_i. In this case, the short message carried by the SS signal has a much lower data rate compared with that of the MC signal.

In one embodiment, short messaging using the SS signaling is performed without close loop power control or time synchronization.

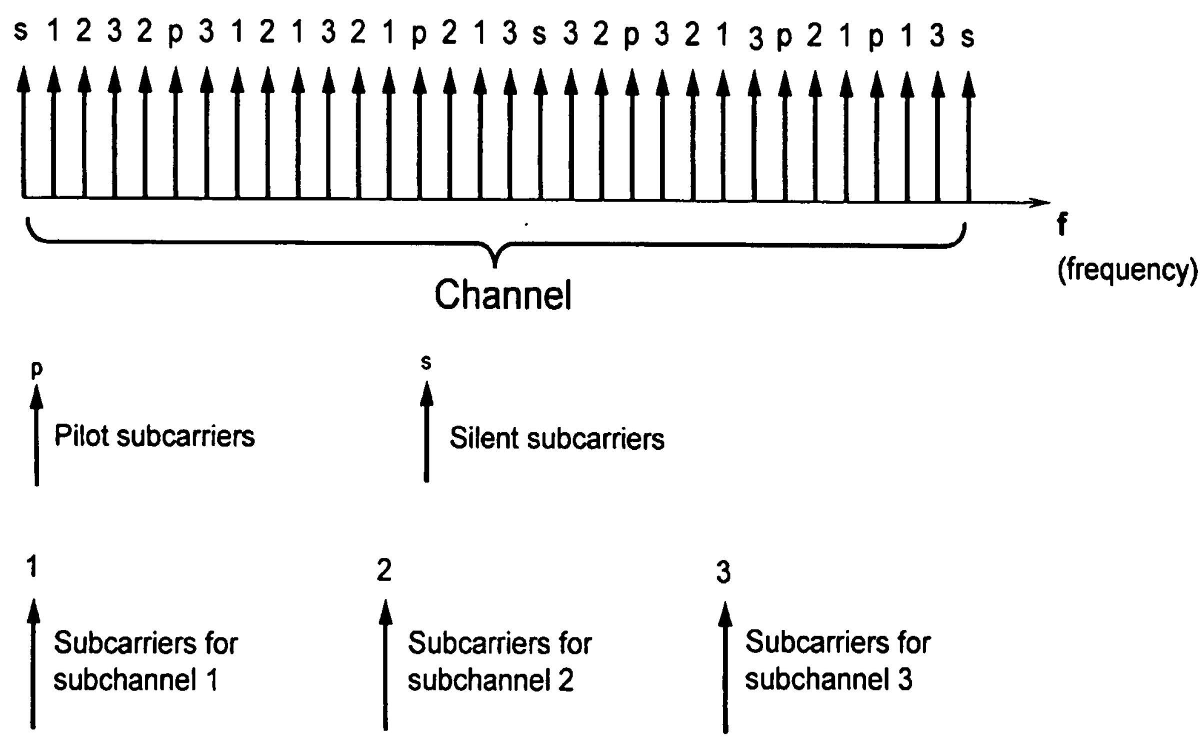

s 1 2 3 2 p 3 1 2 1 3 2 1 p 2 1 3 s 3 2 p 3 2 1 3 p 2 1 p 1 3 s
Channel
f
(frequency)
p
Pilot subcarriers
s
Silent subcarriers
1
Subcarriers for subchannel 1
2
Subcarriers for subchannel 2
3
Subcarriers for subchannel 3

Figure 1

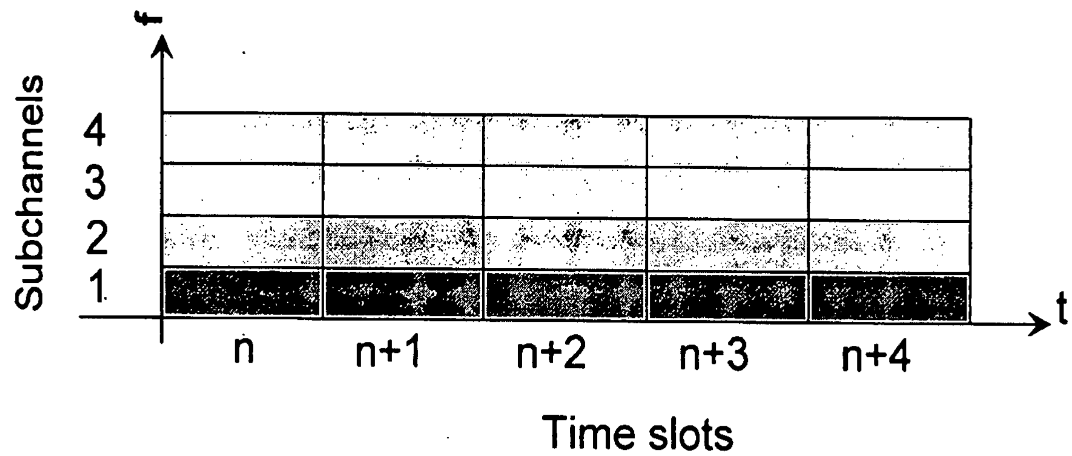
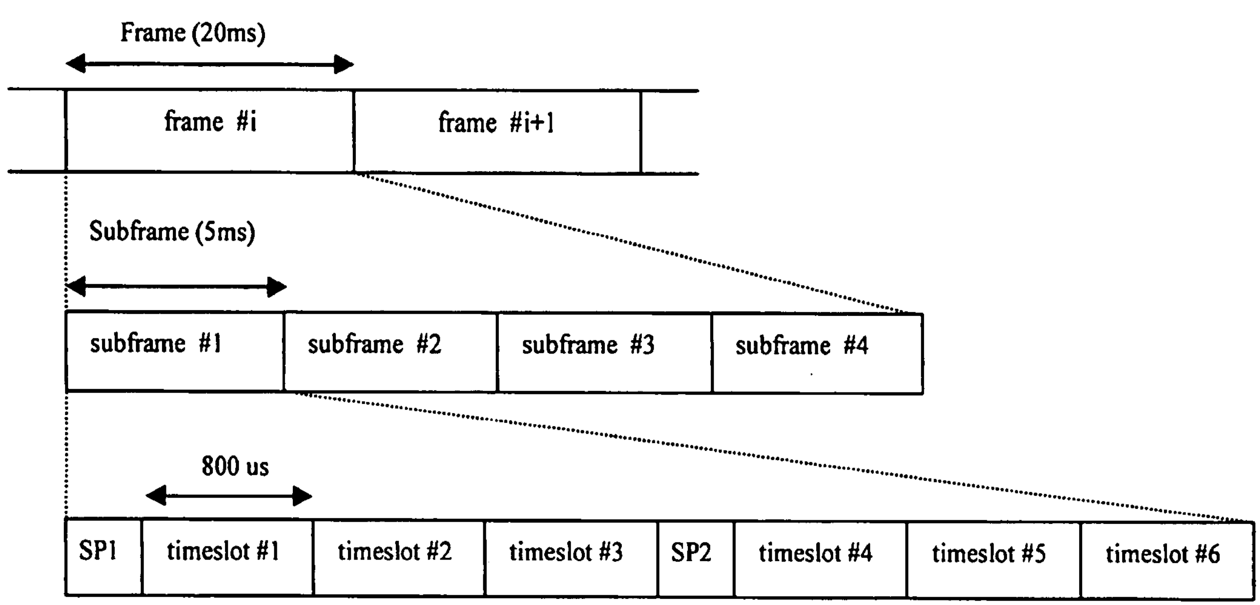
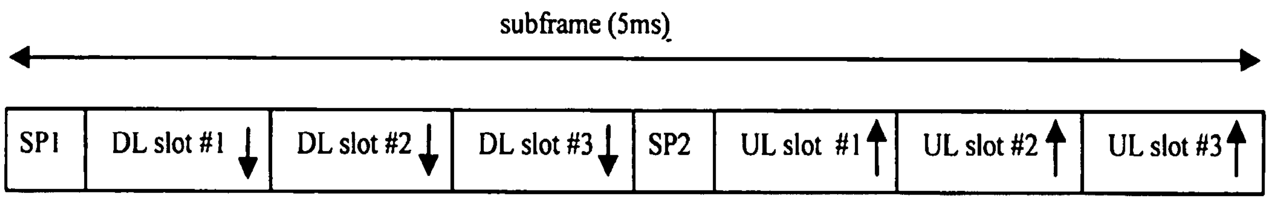


Figure 2

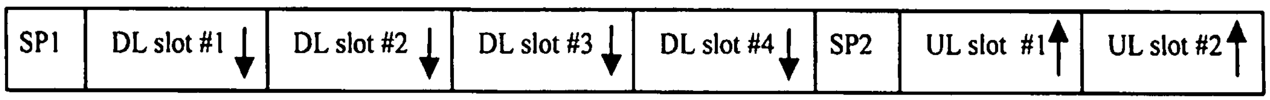


* SP1: Special Period 1
* SP2: Special Period 2

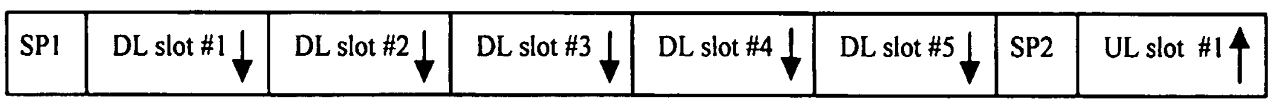
Figure 3



Example Configuration 1: Symmetric (3 DL slots, 3 UL slots)



Example Configuration 2: Asymmetric (4 DL slots, 2 UL slots)



Example Configuration 3: Asymmetric (5 DL slots, 1 UL slots)

Figure 4

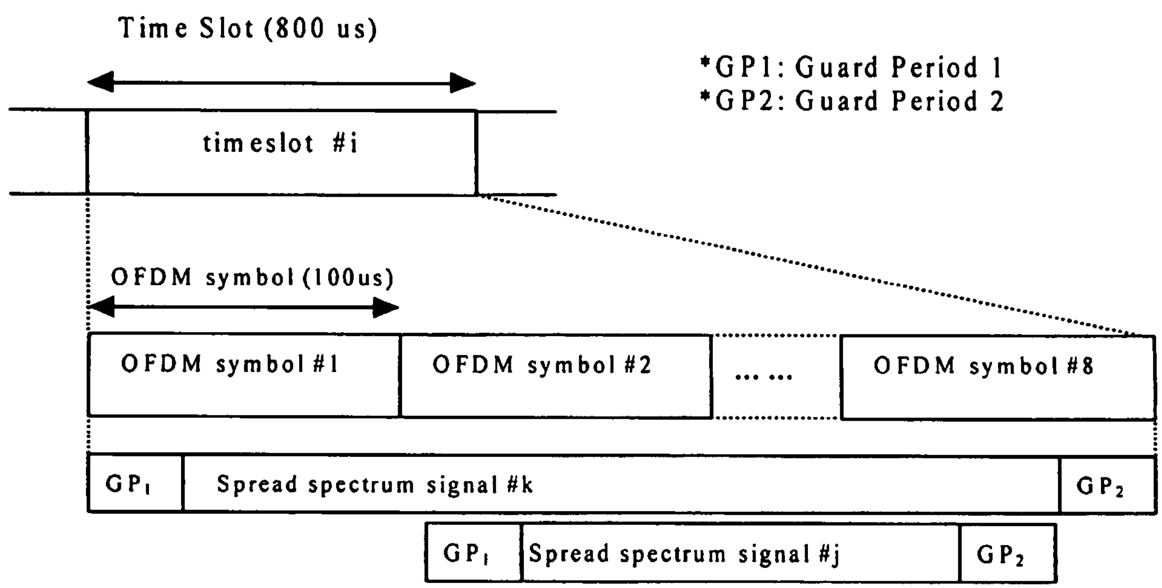

Time Slot (800 us)
*GP1: Guard Period 1
*GP2: Guard Period 2
timeslot #i
OFDM symbol (100us)
OFDM symbol #1
OFDM symbol #2
... ...
OFDM symbol #8
GP1
Spread spectrum signal #k
GP2
GP1
Spread spectrum signal #j
GP2

Figure 5

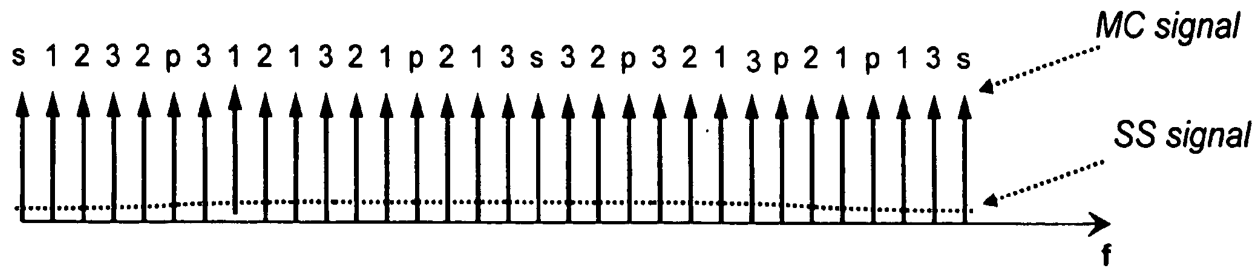


Figure 6

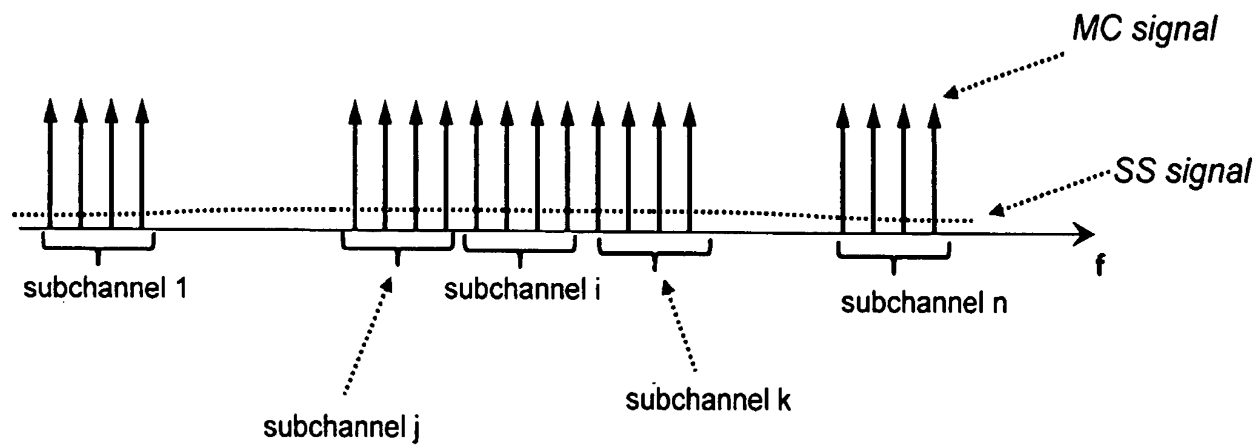

MC signal
SS signal
f
subchannel 1
subchannel i
subchannel n
subchannel j
subchannel k

Figure 7

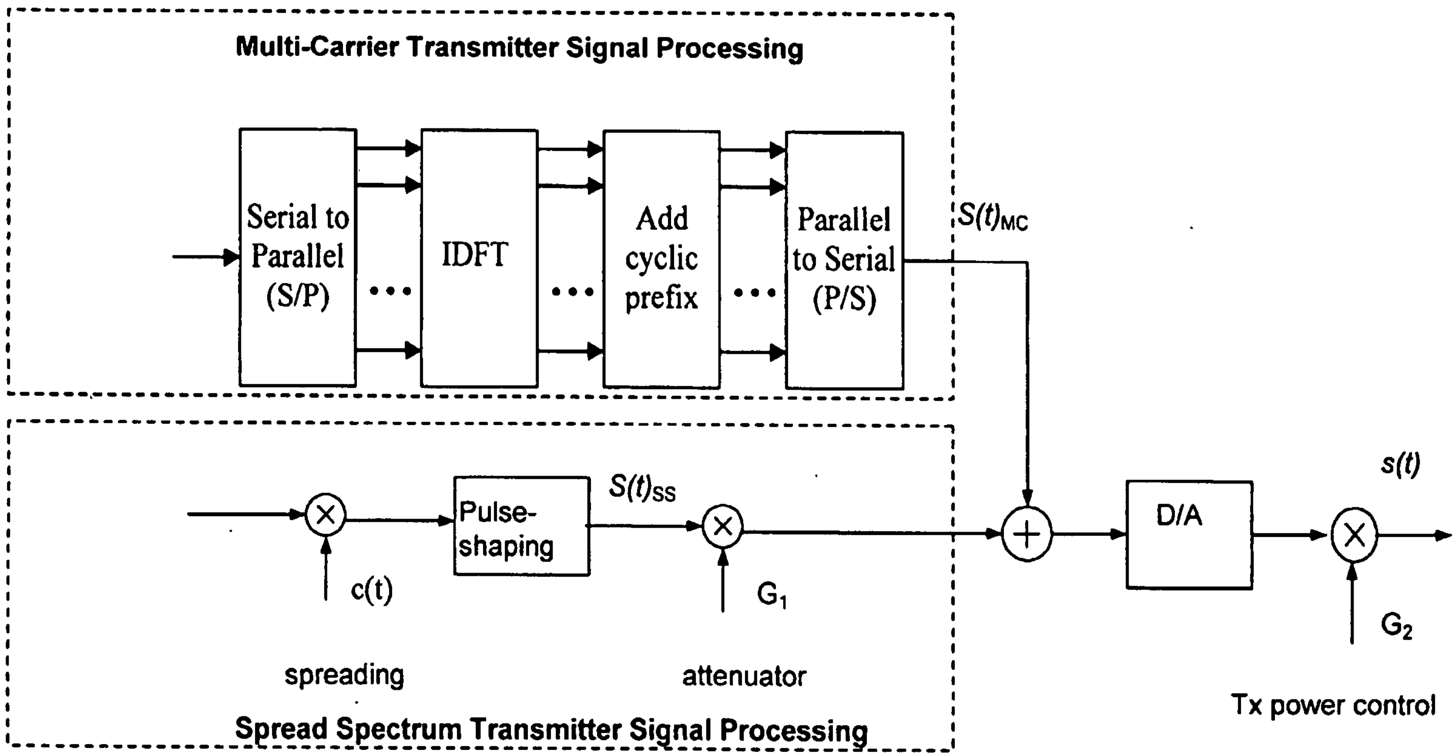
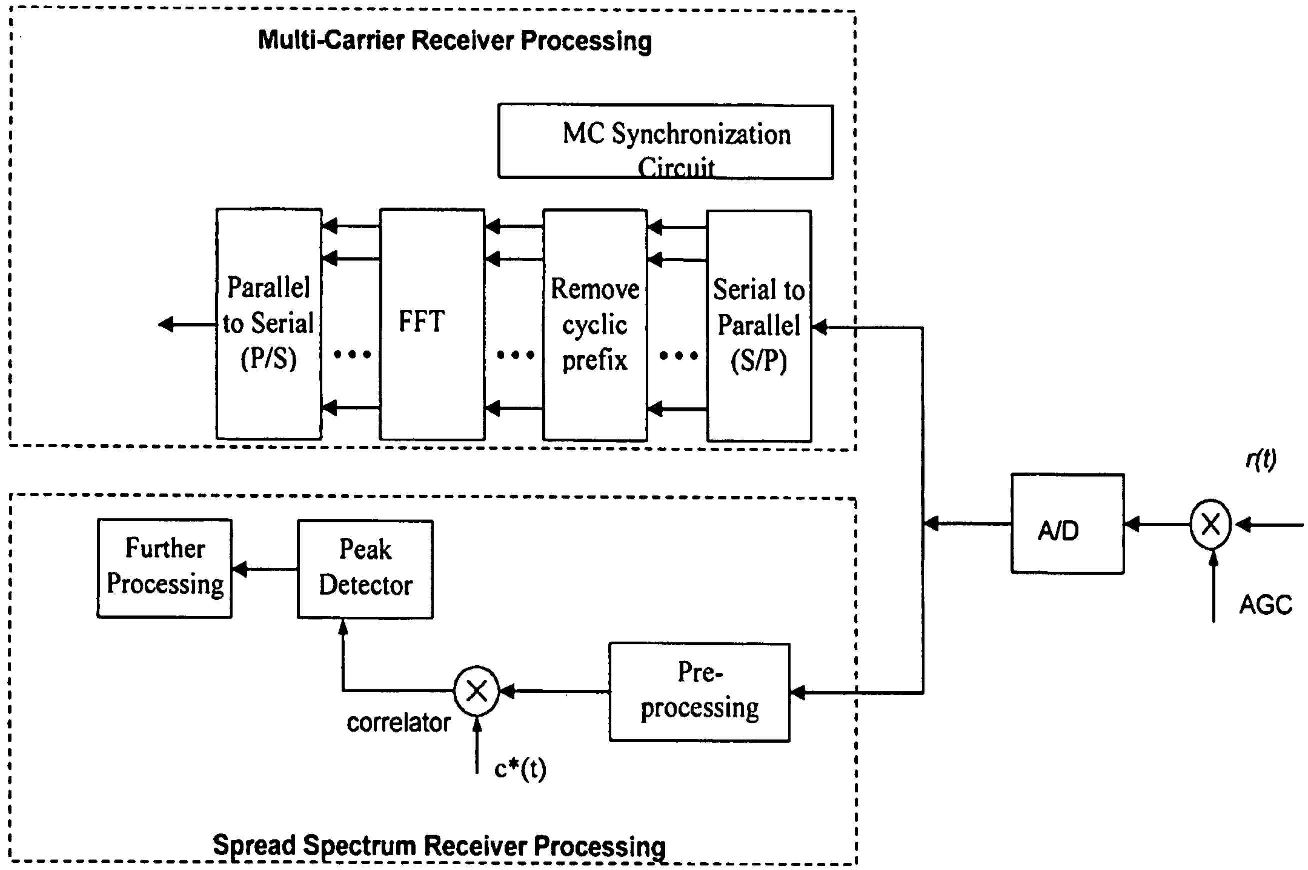

Multi-Carrier Transmitter Signal Processing
Serial to Parallel (S/P)
IDFT
Add cyclic prefix
Parallel to Serial (P/S)
S(t)MC
Pulse-shaping
S(t)SS
c(t)
G1
spreading
attenuator
Spread Spectrum Transmitter Signal Processing
D/A
s(t)
G2
Tx power control

Figure 8



Multi-Carrier Receiver Processing
MC Synchronization Circuit
Parallel to Serial (P/S)
FFT
Remove cyclic prefix
Serial to Parallel (S/P)
r(t)
A/D
AGC
Further Processing
Peak Detector
Pre-processing
correlator
c*(t)
Spread Spectrum Receiver Processing

Figure 9

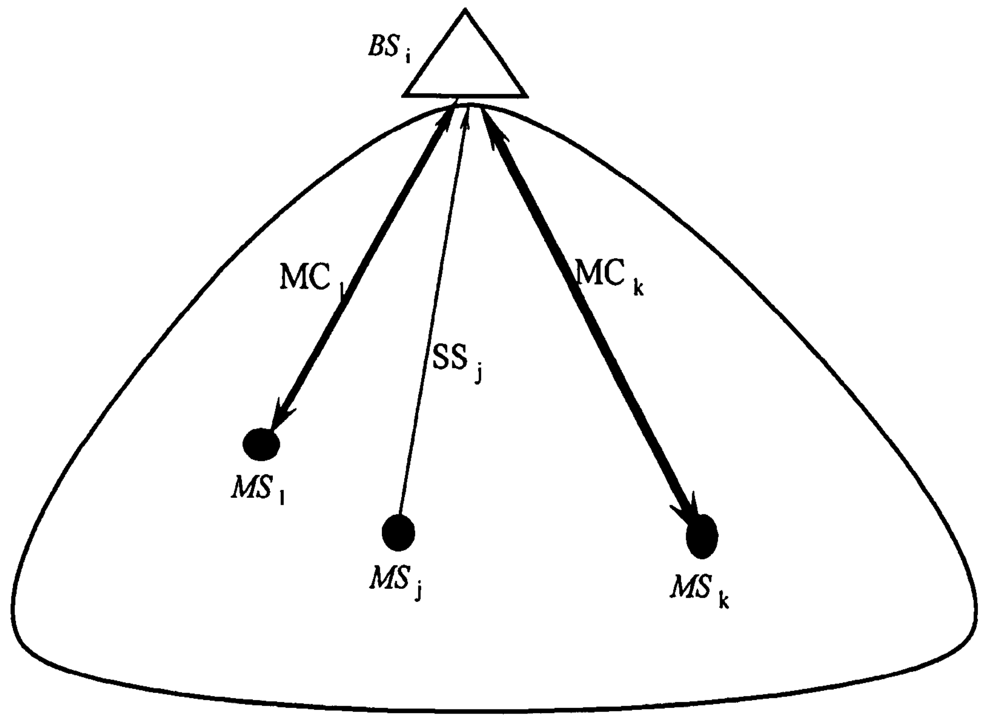


Figure 10

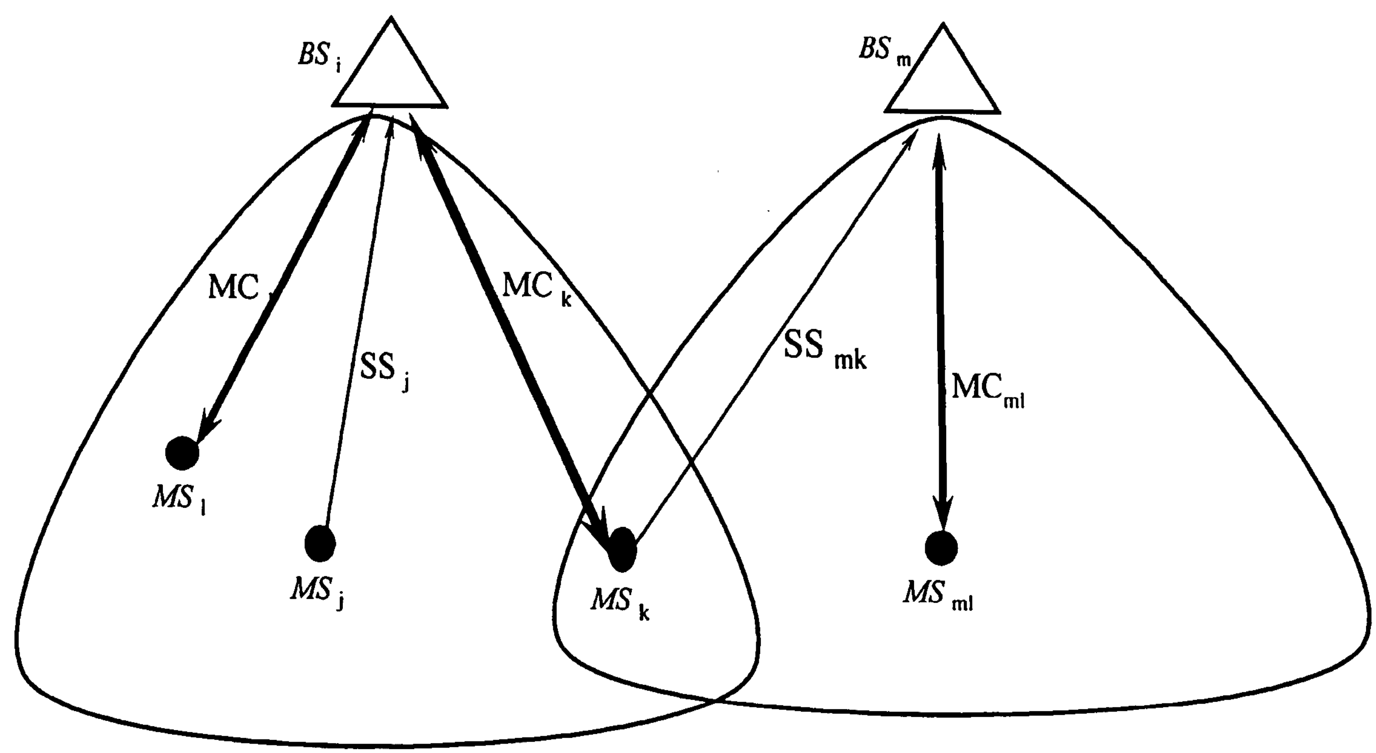
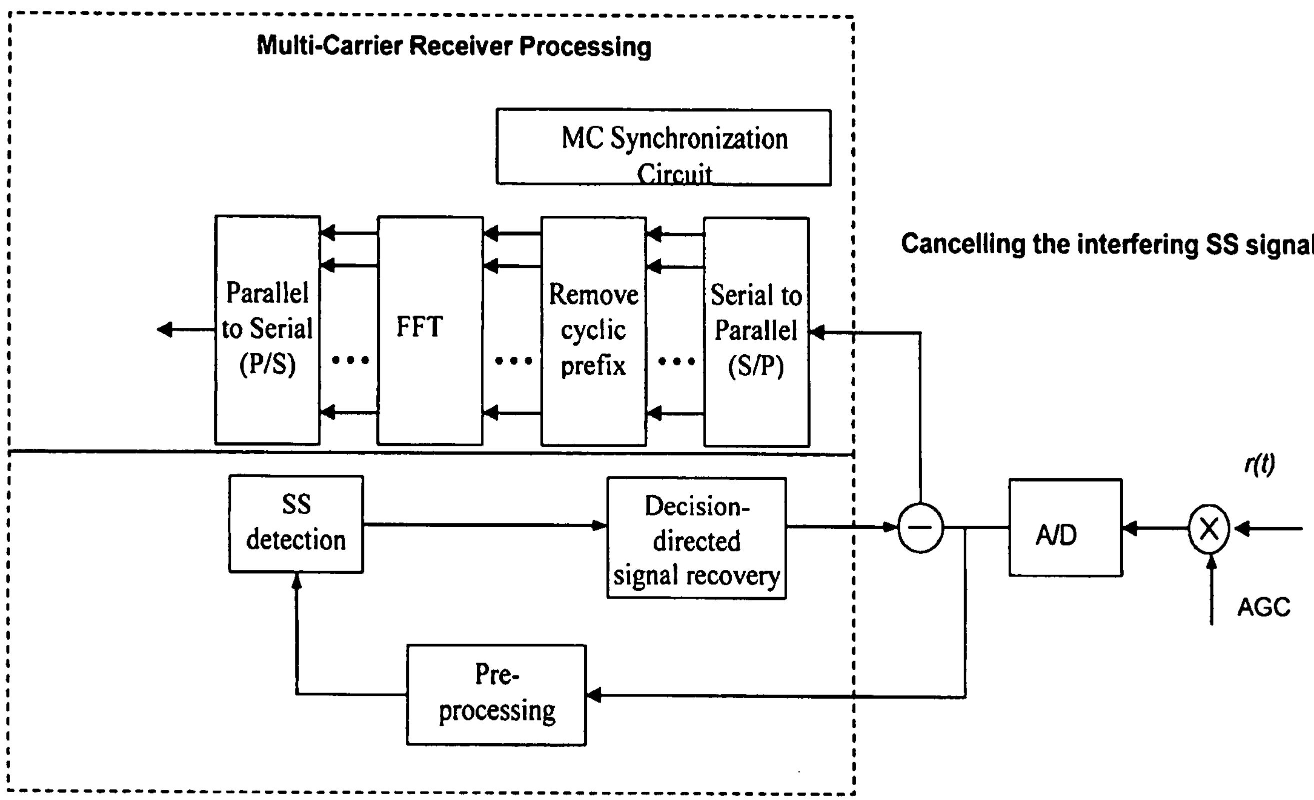


Figure 11



Multi-Carrier Receiver Processing
MC Synchronization Circuit
Parallel to Serial (P/S)
FFT
Remove cyclic prefix
Serial to Parallel (S/P)
Cancelling the interfering SS signal
r(t)
SS detection
Decision-directed signal recovery
A/D
AGC
Pre-processing

Figure 12

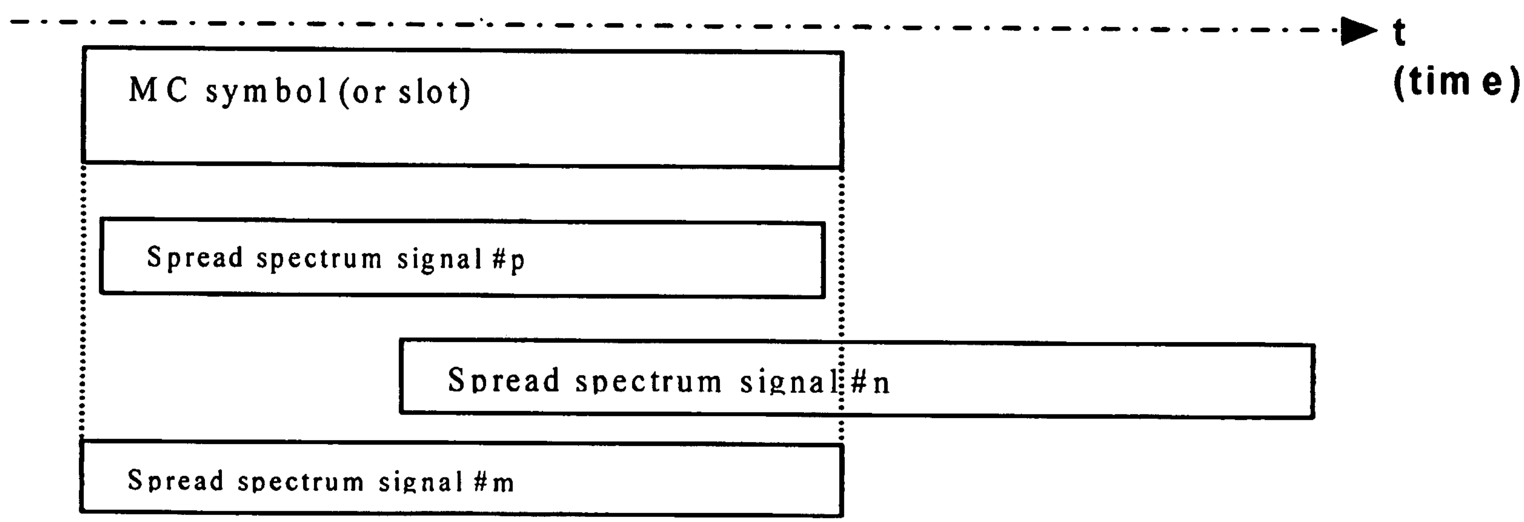

t
(time)
MC symbol (or slot)
Spread spectrum signal #p
Spread spectrum signal #n
Spread spectrum signal #m

Figure 13

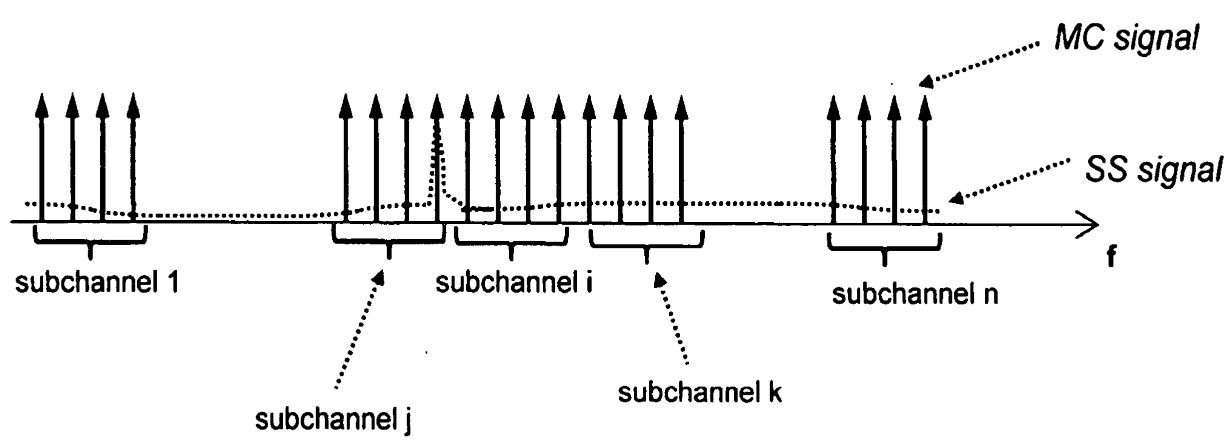

MC signal
SS signal
f
subchannel 1
subchannel i
subchannel n
subchannel k
subchannel j

Figure 14

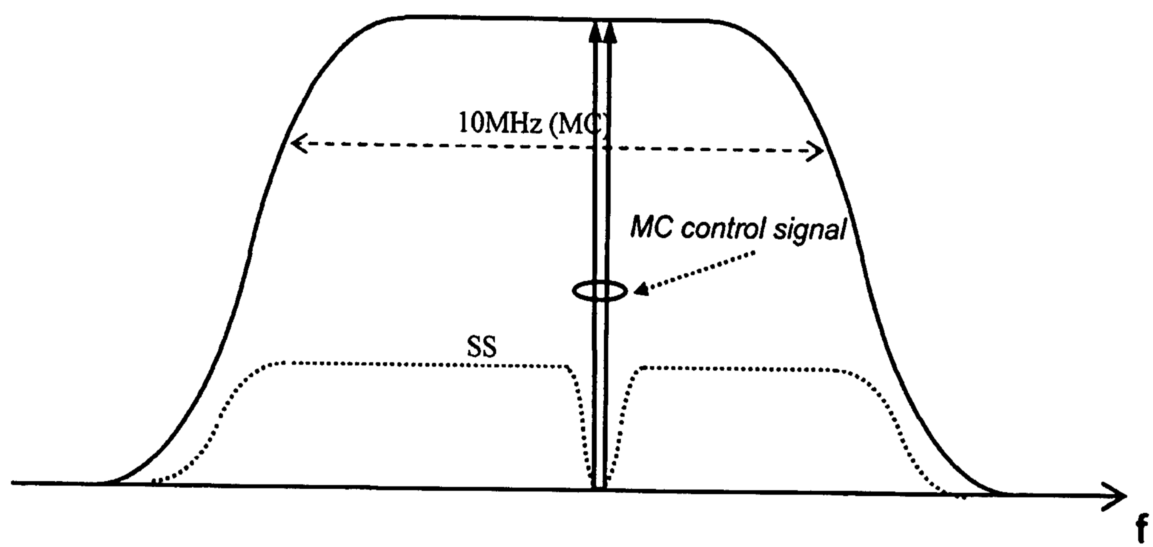


Figure 15

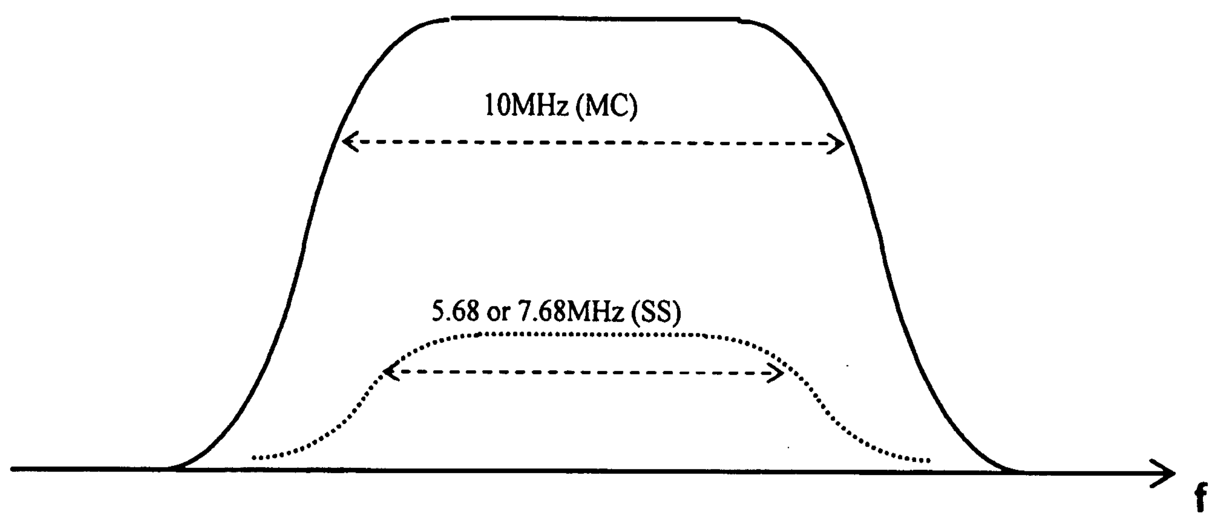


Figure 16

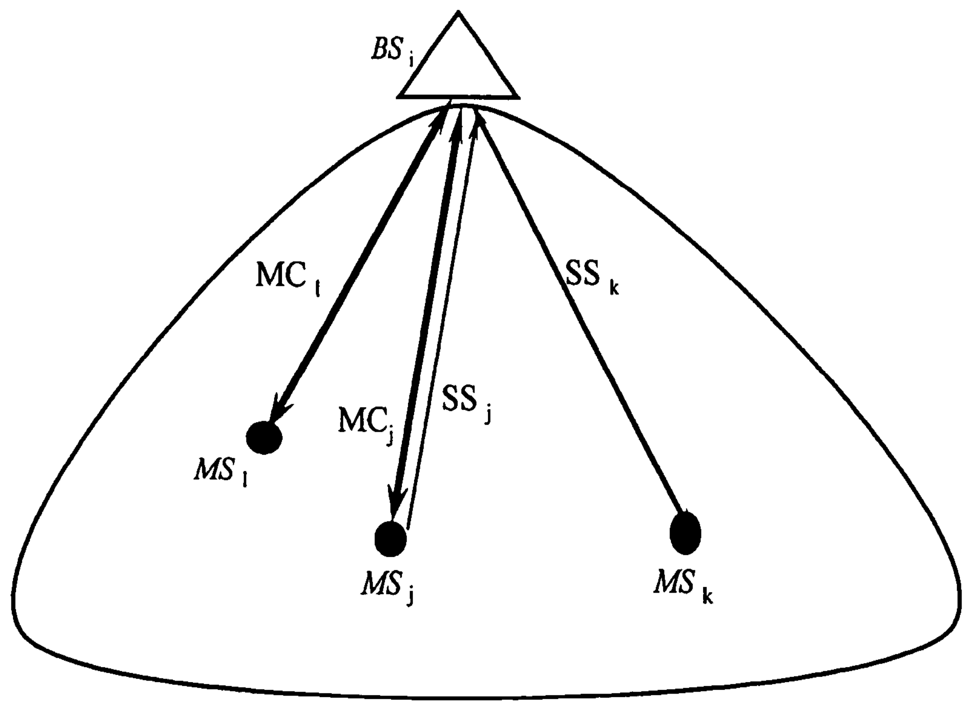
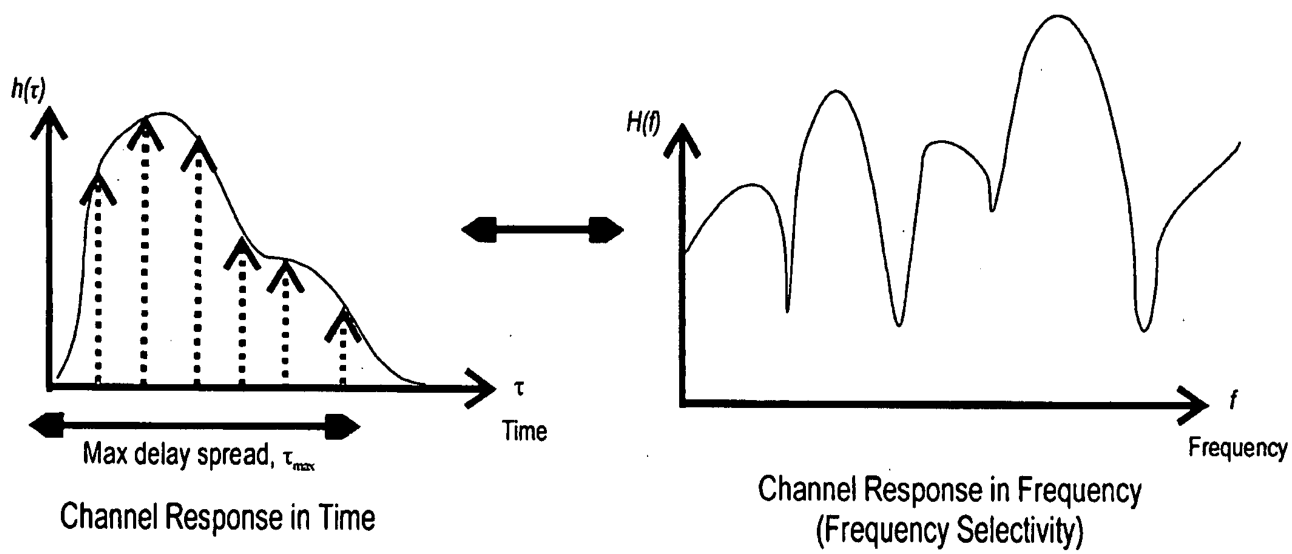


Figure 17



h(τ)
τ
Time
Max delay spread, τ_{max}
Channel Response in Time
H(f)
f
Frequency
Channel Response in Frequency
(Frequency Selectivity)

Figure 18